EXHIBIT H

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Preliminary Report

Sioux Silo Failure Investigation
Tepic, Mexico.

ESI Project: 47623T
AIG Claim: NX0008863
PP REF.: 12465

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Report Submitted to:

Ignacio Perales & Rodrigo Romero
Of Park Perales, S.C

Submitted by:

Francisco J. Godoy, P.E.
Senior Managing Consultant

May 11, 2015
Date

Technical Review by:

Fernando Lorenzo, PhD., P.E.
Principal Engineer.

May 11, 2015
Date

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Introduction

ESI was contacted by Mr. Rodrigo Romero and Mr. Ignacio Perales, from the adjusting company "Park-Perales" (PP), representing the insurance company AIG-USA, and requested to attend his office regarding the investigation of an incident involving the failure of a grain silo that occurred on February 2, 2015, in the State of Nayarit, Mexico.

The silo used to store and handle soybean meal was manufactured by AIG's insured Sioux Steel Company (hereinafter 'Sioux') from South Dakota, USA, and was installed by the Mexican Company 'Molinos Azteca' (hereinafter 'Molinos') at the incident location of the buyer 'Agropecuaria El Avion'. The exact date of the finalization of the installation works of this silo is unknown to ESI, but we were informed that this silo had only recently been installed prior to the incident and, that this accident occurred during the first time that the silo was being operated at almost full capacity. At the time of the incident the silo was loaded with about 681,820.00 Kg (or 1,500,000.00 lb.) of soybean meal (about 93% of its maximum storing capacity for soybean meal). The silo was loaded about four days prior to this incident.

The incident silo was a 30 feet diameter galvanized steel hopper type silo (with 12 rings on the Cylindrical section) supported on 20 steel columns. The hopper was conical with 45° slope with a central discharge (see Fig. 1). The failure occurred when the conical hopper laminates split open causing the sudden spill of the soybean meal underneath the silo, thereby burying two 'Agropecuaria El Avion' workmen who were operating the silo at that time; and resulting in the demise of both workers as a consequence of this failure.

The main purpose of our assignment was to investigate the root cause of the failure of this referenced silo and to identify from an engineering perspective if the failure was due to any defective design, defective installation and/or operation. For that purpose we travelled to the site of the incident to perform an inspection on March 30, 2015. At that inspection we were accompanied by Javier Perez of 'Molinos'. We first met with Mr. Miguel Castro Monroy at the headquarters of 'Agropecuaria El Avion' who is one of the owners and executive of this company. Thereafter we were directed to the location of 'Agropecuaria El Avion' where the silo was installed. The area underneath the silo was cordoned off due to the local district attorney investigation process; but we had the opportunity of taking several pictures and documenting accident related features.

After the incident area was cleared by the Mexican authorities and all the remaining spilled soybean meal was removed, we performed a second inspection on April 28, 2015. Prior to this latest inspection, we prepared and submitted a protocol of inspection in order to notify and describe to the owner of the silo the extent of the inspection. In this second inspection we had complete access to inspect all parts of the failed silo and also collect some samples of the hopper section; as stated in the inspection protocol. We then requested from the insured 'Sioux' and installer 'Molinos' several documents, including the original structural calculations, that were necessary in order to follow-up with our investigation.

After review of the documents provided with regard to that petition, engineering analysis and based on our experience on similar cases we now provide our preliminary report of our findings as follows.

Background

Equipment Description:

As stated above the incident Sioux grain bin was a 30 feet diameter galvanized steel hopper type silo (with 12 rings on the cylindrical section) supported on 20 steel columns; which was assembled at the site by 'Molinos Azteca'. The assembling procedure consisted of erecting the different parts by bolting them together (see Fig. 2).

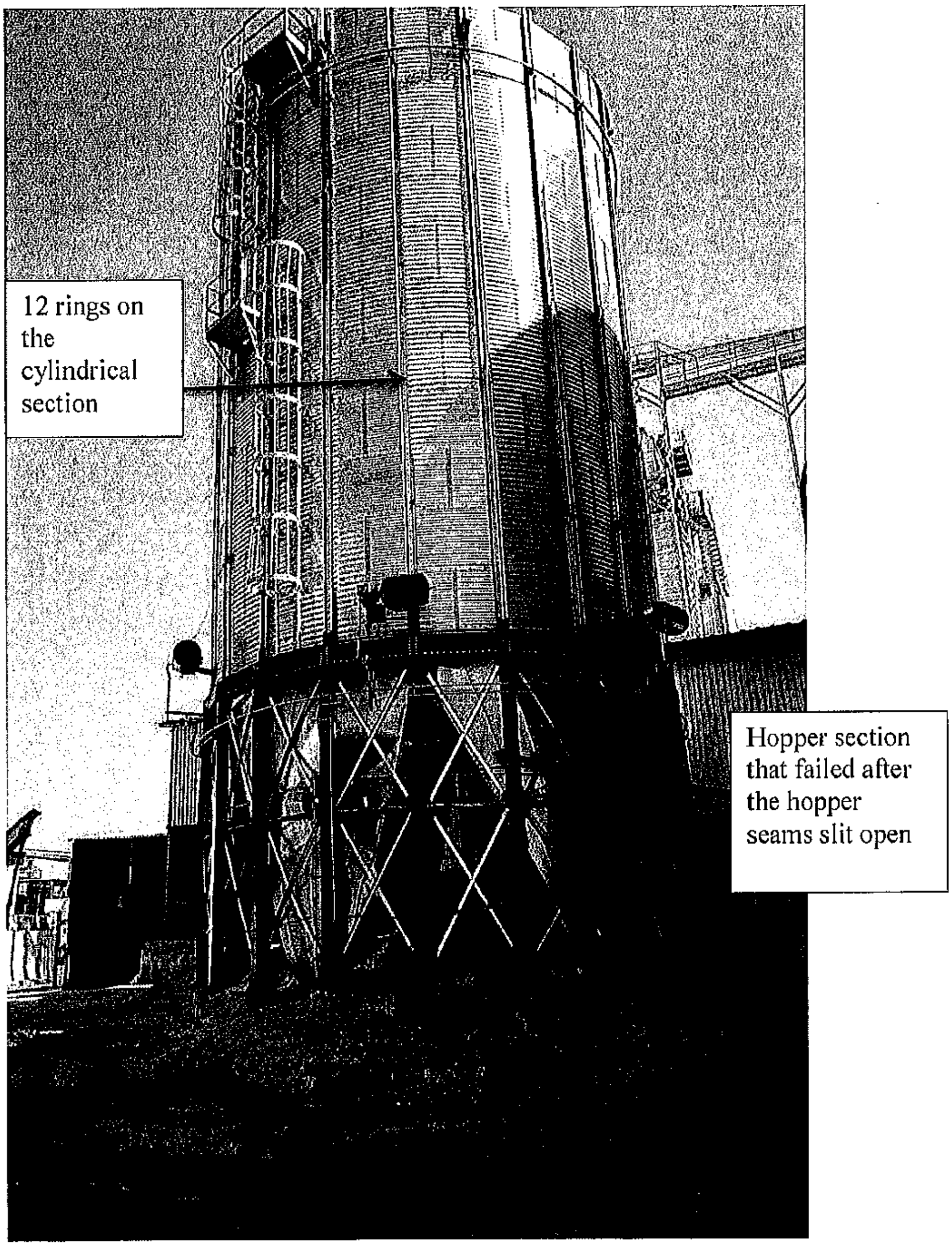

Fig. 1: View of the 30' diameter Sioux failed silo.

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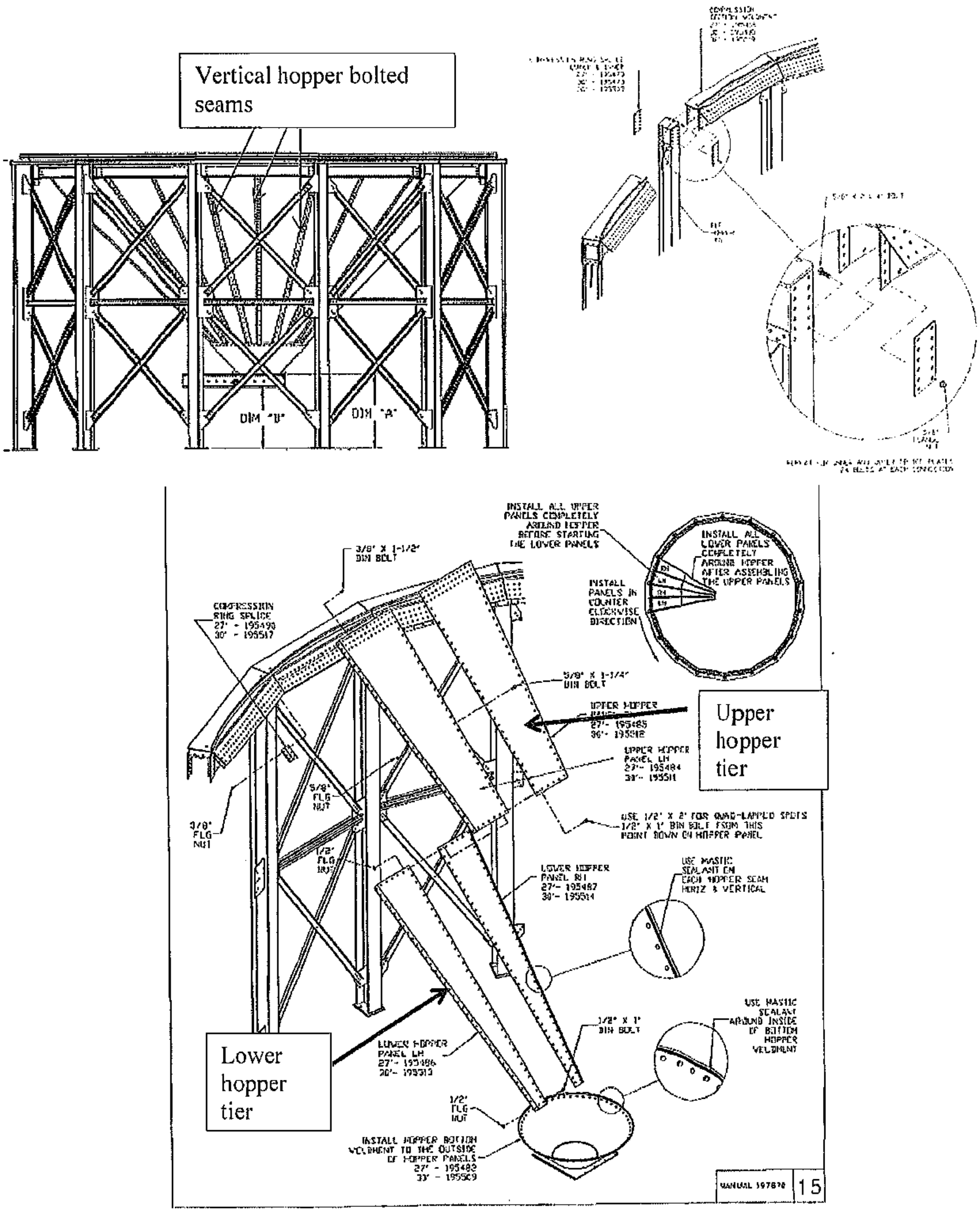

Fig. 2: Illustration of the assembled parts of the Sioux hopper silos. Sioux Manual No. 197870.

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It is important for the purpose of the analysis developed in this report to provide details of the assembly of the hopper section of this grain bin; the part that failed. As can be seen from the illustration of Fig. 2, the 30' conical hopper is assembled by using two tiers of trapezoidal shaped panels or laminates (denominated upper hopper and lower hopper) which are bolted together around the edges to adjacent ones to form the cone (bearing type connection). The bottom section of the lower tier of laminates is bolted/connected to the top perimeter of the bottom central discharge cone.

According to the manufacturer Sioux the volumetric capacity of this 12 rings bin is 36,102 Cubic Feet (CF) or 3,022 Cubic Meters (CM). This bin was being used to handle soybean meal with a density of approximately 720Kg/m3 (Kilograms per cubic meter) or 44.95PCF (pounds per cubic feet) (see Fig. 3); therefore, its maximum capacity would be 735,840 Kgs or 1,618,848 lbs.

Sioux Steel 45 Degree Hopper Cones

Configuration		Height				Weight			Volume		Capacity	
Dia.	Rings	Cone (ft.)	Eave (ft.)	Peak (ft.)	Peak (m)	Cone Weight	Bin Weight	Bin & Cone Weight	ft^3	m^3	Bushels	Metric Tons (769 kg/m³)
30	6	17'-0"	39'-0"	48'-2"	14.68	23798	7822	31620	20716	587	17645	451
30	7	17'-0"	42'-8"	51'-10"	15.80	23798	8994	32792	23280	659	19829	507
30	8	17'-0"	46'-4"	55'-6"	16.92	23798	9901	33699	25844	732	22014	563
30	9	17'-0"	50'-0"	59'-2"	18.03	23798	11263	35061	28409	804	24198	619
30	10	17'-0"	53'-8"	62'-10"	19.15	23798	12452	36250	30973	877	26382	674
30	11	17'-0"	57'-4"	66'-6"	20.27	23798	14067	37865	33538	950	28567	730
30	12	17'-0"	61'-0"	70'-2"	21.39	23798	15462	39260	36102	1022	30751	786
30	13	17'-0"	64'-8"	73'-10"	22.50	23798	16891	40689	38667	1095	32935	842
30	14	17'-0"	68'-4"	77'-6"	23.62	23798	18209	42007	41231	1168	35120	898

Fig. 3: Capacity chart of some 30' diameter Sioux hopper silos.

According to the Sioux drawings for this grain bin the hopper panels are made of a 10 Gauge (GA) (or 0.1345 in) grade 50 steel laminates.

The referenced hopper-silo was furnished with ten (10) air cannons, six (6) on the bottom of the cylindrical part of the silo (top ones) and four (5) on the hopper section (bottom ones) to help and procure the flow of the stored material out from the bottom of the silo (see Fig. 4). The working mechanism of these cannons is configured in such a way that they operate spurting/discharging dry air (stored pressurized at 140 psi per container) into the interior of the silo, and they are triggered consecutively counter-clockwise every 20 seconds, first the top ones and then the bottom ones, with the purpose of producing a motion of the soybean meal (in this case) which is driven by the air flows at the bottom section of the silo in order to propel/procure the material discharge through the opening of the central bottom cone of the hopper. At this plant, the discharged soybean meal was intended to feed another conveyor, installed at the base of this silo, in order for it to be transported to another part of the plant for further processing.

Accident Description:

On Wednesday, January 28, 2015 the referenced silo had been filled with approximately 681,820 Kgs (1,500,000 lbs) of soybean meal which would be about 93% of maximum silo capacity. The soybean meal was left in repose (stationary) in the bin until Monday February 2, 2015, when it was decided to discharge this material for further processing.

That discharge operation started at about 7:30 am, after the silo discharge mechanism (compressed air through the cannons) was activated to discharge the soybean meal through the bottom of the hopper on the conveyor underneath this hopper in order to be transported to another part of the plant for further processing.

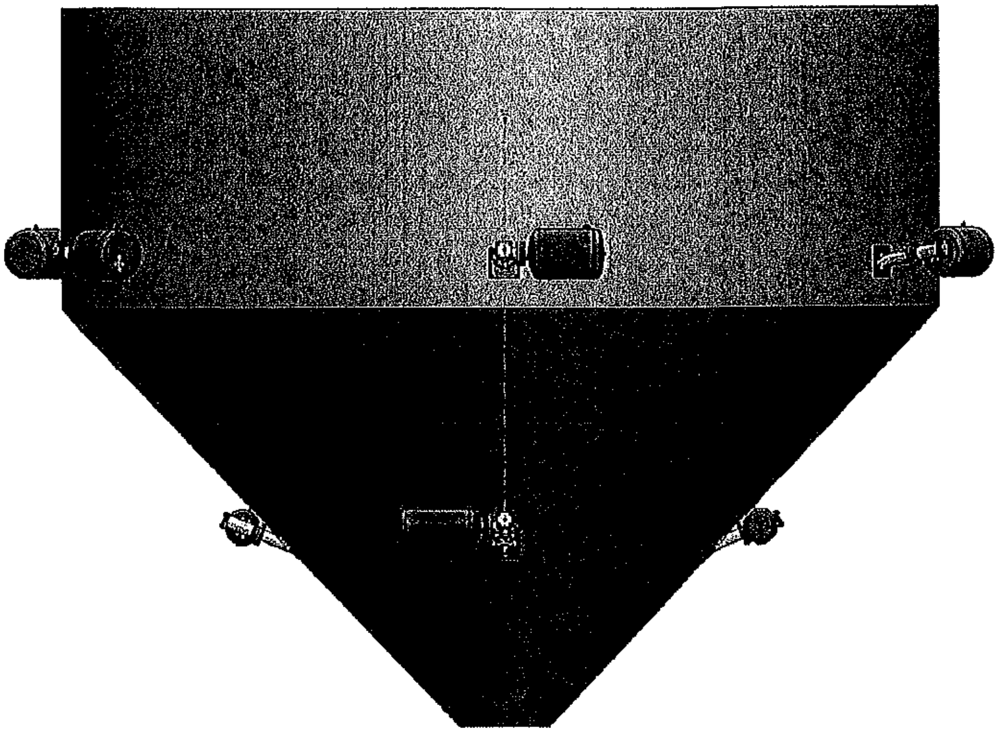

Fig. 4: Air cannons location on the referenced silo.

There were two workers under the bin hopper assisting in the discharge operations of the silo; as the control panels for the silo and the reclaim conveyor were located in that area. About 10 minutes after the discharging process had started the silo hopper split open (see Fig. 1) spilling the soybean material underneath the hopper. The two workers were then buried under the spilled soybean meal; resulting in their demise.

Investigation

Root Cause of Failure:

After examining the failed hopper, it could be corroborated that the hopper shell split open at the seams (see Fig. 5). As can be observed from the pictures of Fig. 5, it is evident that some fasteners used to attach together the hopper laminates tore through the ends of the laminates' edges causing a bearing type of failure of the bolted joint due to shear stresses (on the laminate edges). Therefore, it is clear that hoop stresses (or circumferential stresses) acting perpendicular to the seams, pulled those seams apart and then caused the failure of some bolted joints at those seams of the hopper. Following are the circumstances that led to that failure.

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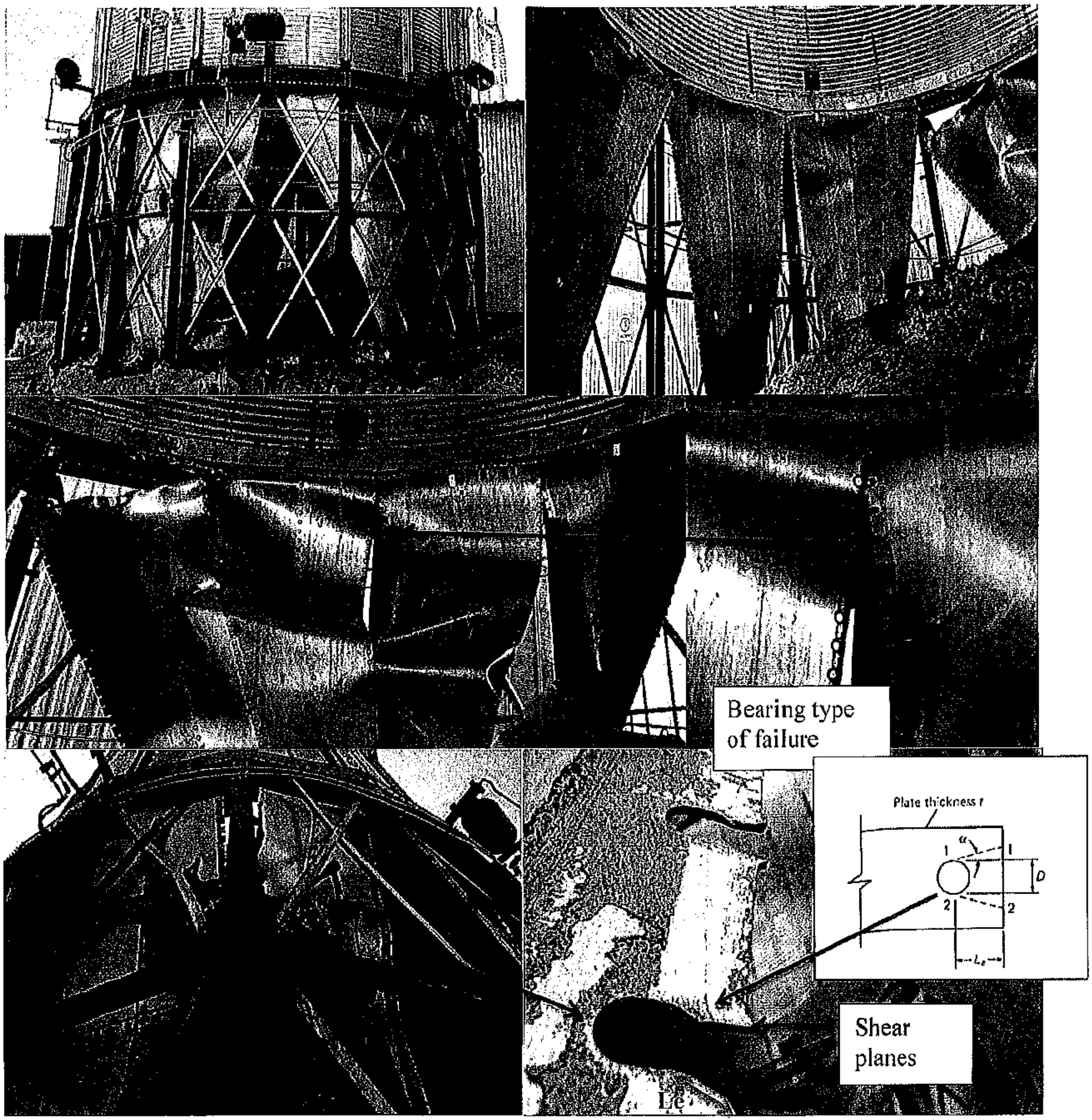

Fig. 5: Photo of the hopper failure.

a) Stresses on the Referenced Hopper:

When a silo is filled with any bulk material (such as grains or meal) pressure and consequently stresses are produced or generated on the shell of the bin (see Fig. 6). It is not the intent of this report to provide a detailed description of the mechanism of the pressures and stresses produced on the structure of the hopper shell due to those pressures but rather to illustrate and calculate the real stresses (magnitude) that existed at the moment of the failure of the referenced hopper. The stresses on a hopper silo are well described in the references provided at the end of this report (Ref. 1 to 11). Basically, all the calculations of pressure on silos are based on the 'Janssen silo pressure theory' (Janssen equations).

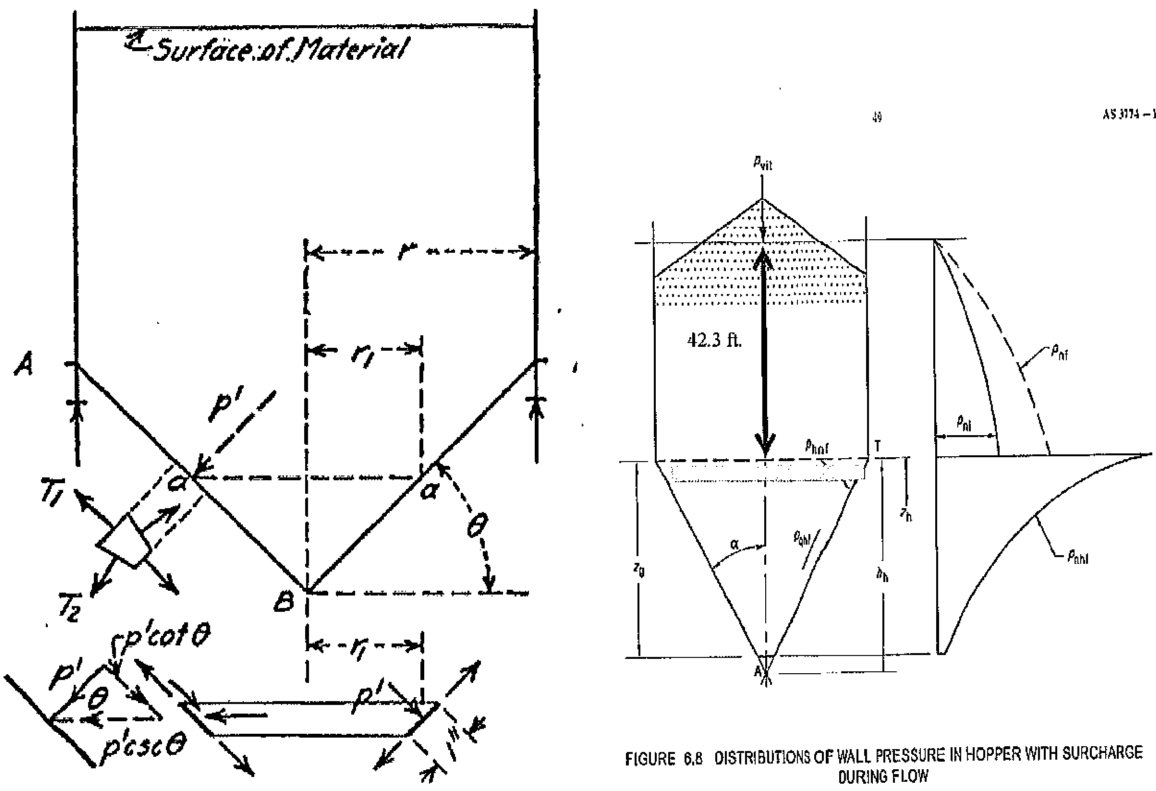

Fig. 6: Pressures on the hopper shell during flow.

The pressures and also in effect the stresses on the hopper wall or shell are different from when the stored material is in stationary mode or condition to the condition; to those of when that material is being discharged or funneled. Fig. 6 shows the normal pressure on the bin walls abruptly increases during the transition from the cylindrical part of the bin to the conical part of the bin; during flow of the material (or funneling condition).

The accident occurred when the material was being funneled or discharged. Based on the loading of the silo reported at 93% of full capacity at the time of the accident, the material height in the cylindrical part of the bin was at about 42.5 ft. Therefore, ESI calculated the actual pressure that was being exerted on the bin hopper by the material at those conditions at the time of the failure. Table 1 and Table 2 below show those pressures by using two different approaches from Ref. 1 and Ref. 2.

Table 1: Structural Analysis for the hopper section of the referenced silo based on the method from reference 'The Design of Walls, Bins and Grain Elevators' by Milo Smith Ketchum.

D=	30	ft			1-kg/m3=	0.062428	pound per (cubic ft)	
Soybean Meal Data:								
Density:	720	Kg/m3	Sin(θ+ϕ)=	0.966	Vmax	1,022	m3	
Density-w:	44.9	Lb/ft3	Sin(θ)=	0.707				
k=	0.481		Sin(ϕ)=	0.500				
Rh=	7.5	ft	: R1 p' /Sin(θ)					
ϕ=	30		ΔL=	3	in			
ϕ'=	12.4		Th=	0.1345	in			
μ=	0.58		Fu=	65	Ksi			
μ'=	0.22							
θ=	45	Hopper Cone Angle						
H(ft)	**V(psf)**	**V(psi)**	**p(psi)**	**σ (psi)**	**P(lb)**	**Leactual (in)**	**Lereq (in)**	
1.5	66.7	0.46		H=(V-π R³/3)/πR²				
6.5	279.2	1.94						
11.5	477.1	3.31		Vm=	36102	ft3		
16.5	661.6	4.59		V=	93	%		
21.5	833.6	5.79		V=	33574.86	ft3		
26.5	993.8	6.90		H=	42.5			
31.5	1143.1	7.94						
36.5	1282.2	8.90						
41.5	1411.9	9.80						
42.5	1436.7	9.98	9.03	12091.36	4878.9	0.56	1.12	
43.5	1461.2	10.15	9.19	11477.74	4631.3	0.53	1.06	
44.5	1485.4	10.32	9.34	10834.12	4371.6	0.50	1.00	

Table 1. Range of published physical properties of grains and oilseeds.

Parameters	Grain/Oilseed Kernels: Soybean		Corn		Wheat	
Moisture content (% w.b.)	6.9-16.7	[b, j, k, p, s, t, y, z]	6.7-25.0	[e, f, h, k, s, y, z, aa]	6.2-20.0	[e, f, g, k, t, y, z, aa]
Particle length (mm), l	7.0-8.2	[q, s, t, y]	9.4-20.3	[k, s, u, y, ac]	5.5-7.3	[k, s, y]
Particle width (mm), w	6.1-6.7	[q, s, t, y]	6.0-16.4	[k, s, u, y, ac]	2.6-3.8	[k, s, y]
Particle thickness (mm), h	5.5-5.9	[q, s, t, y]	4.0-12.5	[k, s, u, y, ac]	2.4-3.5	[k, s, y]
Particle equivalent diameter (mm), d_e	6.0	[k, w]	8.0	[k]	3.6-4.1	[k]
Particle radius (mm), r_e	3.0	[k, w]	4.0	[k]	1.8-2.1	[k]
Particle mass (mg), m	100-200	[q, s, x, t, y]	250-340.7	[c, k, l, s, u, y]	26-51	[k, l, c, s, y]
Particle volume (mm³), V	134.1-152.8	[s]	274	[p]	18.5-28.6	[s]
Particle density (kg m⁻³), ρ_p	1130-1325.2	[p, s, w, y, z]	1270-1396.5	[k, s, y, z, ac]	1290-1430	[k, s, y, z]
Bulk density (kg m⁻³), ρ_b	705-876	[i, p, s, y, z]	661-810	[i, k, l, s, y, z]	690-813.2	[i, k, l, s, y, z]
Particle Poisson ratio, ν	0.08-0.4134	[i, q, t, w, y]	0.17-0.4	[a, k, v, y, aa, ac]	0.16-0.42	[s, y, aa]
Particle elastic modulus (MPa), E	31.2-176.9	[i, t, w, y]	10.9-2320	[a, v, y, aa, ac]	10-2831	[s, y]
Particle shear modulus (MPa), G	13.3-63.2	[i, t, w, y]	4.5-828.6	[a, v, y, aa, ac]	4.2-997.9	[s, y]
Particle restitution coefficient, e						
Generic	0.5, 0.7	[m, q]	--		--	
With aluminum	0.6, 0.7	[p]	--		--	
With acrylic	--		0.59	[aa]	--	
Particle static friction coefficient, μ_s						
With self (grain)	0.267, 0.55	[q, d, k]	0.32, 0.53	[a, d, k]	0.47, 0.53	[a, b, d, k]
With galvanized sheet (or sheet metal)	0.18-0.27	[i, k, y]	0.20-0.34	[i, k, y]	0.10-0.44	[i, k, y]
With steel (or stainless steel)	0.223-0.247, 0.37	[c, d, k]	0.235-0.76	[a, d, e, k, v, y]	0.248-0.55	[a, b, d, e, k, y]
With transparent perspex	0.30	[w]	--		--	
With aluminum	0.329, 0.366	[p]	0.226-0.276	[v]	--	
With acrylic	0.326, 0.332	[p]	0.34	[l]	--	
With glass	0.327, 0.328	[p, q]	--		--	
Bulk angle of repose (°)						
For filling or piling (also called dynamic angle)	16	[d, k]	16	[d, k]	16	[d, k]
For emptying or funneling (also called static angle)	29-33	[d, k, y]	23.1-34.7	[d, k, y]	23.8-38.1	[d, k, y]

$$V = \frac{w.R}{k.\mu'}\left(1 - e^{-\frac{k.\mu'.h}{R}}\right)$$

$$L = k.V,$$

$$L = \frac{w.R}{\mu'}\left(1 - e^{-\frac{k.\mu'.h}{R}}\right)$$

$$p' = V \frac{\sin^2(\theta + \phi)}{\sin^3\theta\left(1 + \frac{\sin\phi}{\sin\theta}\right)^2}$$

Nomenclature: The following nomenclature will be used:

ϕ = the angle of repose of the grain;
ϕ' = the angle of friction of the grain on the bin walls;
$\mu = \tan\phi$ = coefficient of friction of grain on grain;
$\mu' = \tan\phi'$ = coefficient of friction of grain on the bin walls
x = angle of rupture;
w = weight of grain in lbs. per cu. ft.;
V = vertical pressure of the grain in lbs. per sq. ft.;
L = lateral pressure of the grain in lbs. per sq. ft.;
A = area of bin in sq. ft.;
U = circumference of bin in feet;
$R = A/U$ = hydraulic radius of bin.

Table 4. Experimental values for stress ratio (k) and predicted values calculated using equations 10, 11, and 12 for wheat, soybean meal, and corn meal.

	Experimental	Eq. 10	Eq. 11	Eq. 12
Wheat	0.355	0.235	0.498	0.666
Soybean meal	0.481	0.351	0.359	0.491
Corn meal	0.333	0.266	0.365	0.500

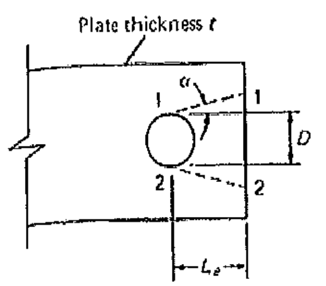

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Table 2: Structural Analysis for the hopper section of the referenced silo based on the method of the Australian Standard 'Loads on Bulk Solids Containers'.

D= 30 ft					1-kg/m3=	0.062428	pound per (cubic ft)
Soybean Meal Data:							
Density:	720	Kg/m3	Sin(θ+ϕ)=	0.966			
Density-w:	44.9	Lb/ft3	Sin(θ)=	0.707			
k=	0.481		Sin(ϕ)=	0.500			
Khf=	0.85	ϕw=	20	degrees			
Ch=	2	j=	0.074				
Rh=	7.5	ft	τ= R1 p' /Sin(θ)				
ϕ=	30	Internal	ΔL=	3	in		
ϕ'=	12.4	Wall	Th=	0.1345	in		
μ=	0.58	Internal	Fu=	65	Ksi		
μ'=	0.22	Wall					
θ=	45						

H (ft)	pv1 (psf)	pv1 (psi)	pn1 (psi)	σ (psi)	P (lb)	Leactual (in)	Lereq (in)
1.5	66.7	0.46		$H=(V-\pi R^3/3)/\pi R^2$			
6.5	279.2	1.94					
11.5	477.1	3.31		Vm=	36102	ft3	
16.5	661.6	4.59		V=	93	%	
21.5	833.6	5.79		V=	33574.86	ft3	
26.5	993.8	6.90		H=	42.5		
31.5	1143.1	7.94					
36.5	1282.2	8.90					
41.5	1411.9	9.80					
42.5	1436.7	9.98	8.48	11349.66	4579.6	0.52	1.05
43.5	1461.2	10.15	8.63	10773.68	4347.2	0.50	0.99
44.5	1485.4	10.32	8.77	10169.54	4103.4	0.47	0.94

AS 3774—1996

6.3.5 Normal pressures on hoppers The normal pressure on the walls of a hopper during flow is non-uniform (see Figure 6.8). The pressure distribution on the hopper shall be determined from the following equation:

$$p_{nf} = k_{hf} p_{vf} \qquad \ldots 6.3.5(1)$$

where

p_{nf} = normal pressure on the walls of a hopper during flow, in kilopascals

k_{hf} = normal pressure ratio for hopper (see Figure 6.10)

$$= \frac{1 + \sin\phi_i \cos(2\eta)}{1 - \sin\phi_i \cos[2(\alpha + \eta)]} \qquad \ldots 6.3.5(2)$$

p_{vf} = vertical pressure in the hopper during flow at any depth z_h below the transition, in kilopascals

$$= \frac{\gamma(h_h - z_h)}{j - 1} + \left(p_{vo} - \frac{\gamma h_h}{j - 1}\right)\left(\frac{h_h - z_h}{h_h}\right)^j \qquad \ldots 6.3.5(3)$$

and where

ϕ_i = lower characteristic value of effective angle of internal friction, in degrees

η = angle variable, in degrees
$= 0.5[\phi_w + \sin^{-1}(\sin\phi_w/\sin\phi_i)]$
$\leq 90°$

α = half-angle for a conical hopper or the angle between the steepest line and the vertical in a pyramidal hopper, in degrees

ϕ_w = lower characteristic value of angle of wall friction, in degrees

γ = unit weight of bulk solid, in kilonewtons per cubic metre

h_h = height of the hopper from the apex to the transition, in metres

z_h = depth below the cylinder to hopper transition, in metres

j = hopper exponent
$= c_h[k_h(\mu_h \cot\alpha + 1) - 1]$

p_{vo} = mean vertical pressure in the bulk solid at the level of the transition determined from Equation 6.2.3.1(1), where $z = h_c + h_s$ (see Figure 2.6), in kilopascals

c_h = hopper geometry coefficient
- 2 for a conical or pyramidal hopper (Type H1)
- 1 for a wedge or slot hopper (Type H2)

μ_h = lower characteristic value of coefficient of wall friction

Table 1. Range of published physical properties of grains and oilseeds.

Parameters	Soybean		Corn		Wheat	
	Grain/Oilseed Kernels					
Moisture content (% w.b.)	6.9-16.7	[illegible]	6.7-25.0	[illegible]	6.2-20.0	[illegible]
Particle length (mm), l	7.0-8.2	[illegible]	9.4-20.3	[illegible]	5.5-7.3	[illegible]
Particle width (mm), w	6.1-6.7	[illegible]	8.0-16.4	[illegible]	2.6-3.8	[illegible]
Particle thickness (mm), h	5.5-5.9	[illegible]	4.0-12.8	[illegible]	2.4-3.5	[illegible]
Particle equivalent diameter (mm), d_e	6.0	[illegible]	8.0	[k]	3.6-4.1	[k]
Particle radius (mm), r_e	3.0	[illegible]	4.0	[k]	1.8-2.1	[k]
Particle mass (mg), m	100-200	[illegible]	250-349.7	[illegible]	26-51	[illegible]
Particle volume (mm³), V	134.1-152.8	[illegible]	274	[illegible]	18.5-28.6	[illegible]
Particle density (kg m⁻³), ρ_p	1120-1325.2	[illegible]	1270-1396.5	[illegible]	1290-1430	[illegible]
Bulk density (kg m⁻³), ρ_b	705-876	[illegible]	661-810	[illegible]	690-823.2	[illegible]
Particle Poisson ratio, ν	0.08-0.4134	[illegible]	0.17-0.4	[illegible]	0.16-0.42	[illegible]
Particle elastic modulus (MPa), E	31.2-176.9	[illegible]	10.9-2320	[illegible]	10-2834	[illegible]
Particle shear modulus (MPa), G	13.3-63.2	[illegible]	4.5-828.6	[illegible]	4.2-997.9	[illegible]
Particle restitution coefficient, e						
Generic	0.5, 0.7	[illegible]	--		--	
With aluminum	0.6, 0.7	[illegible]	--		--	
With acrylic	--		0.59	[illegible]	--	
Particle static friction coefficient, μ_s						
With self (grain)	0.267, 0.55	[illegible]	0.52, 0.51	[illegible]	0.47, 0.53	[illegible]
With galvanized sheet (or sheet metal)	0.18-0.27	[illegible]	0.20-0.34	[illegible]	0.10-0.44	[illegible]
With steel (or stainless steel)	0.223-0.247, 0.37	[illegible]	0.235-0.76	[illegible]	0.248-0.55	[illegible]
With transparent perspex	0.30	[illegible]	--		--	
With aluminum	0.329, 0.366	[illegible]	0.226-0.276	[illegible]	--	
With acrylic	0.326, 0.332	[illegible]	0.34	[illegible]	--	
With glass	0.327, 0.328	[illegible]	--		--	
Bulk angle of repose (°)						
For filling or piling (also called dynamic angle)	16	[illegible]	16	[illegible]	16	[illegible]
For emptying or funneling (also called static angle)	29-33	[illegible]	23.1-34.7	[illegible]	23.8-38.1	[illegible]

calculated using equations 10, 11, and 12 for wheat, soybean meal, and corn meal.

	Experimental	Eq. 10	Eq. 11	Eq. 12
Wheat	0.355	0.235	0.498	0.666
Soybean meal	0.481	0.351	0.359	0.491
Corn meal	0.333	0.266	0.365	0.500

AS 3774—1996

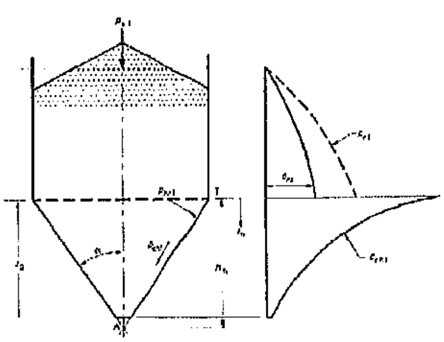
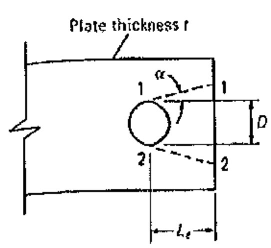


FIGURE 6.8 DISTRIBUTIONS OF WALL PRESSURE IN HOPPER WITH SURCHARGE DURING FLOW



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The pressure exerted on the hopper during the emptying of the material of the silo produces a hoop stress on the circular sections of the hopper. Fig. 7 below shows the formulas for the calculation of the hoop stresses at any circumferential section on the coned hopper.

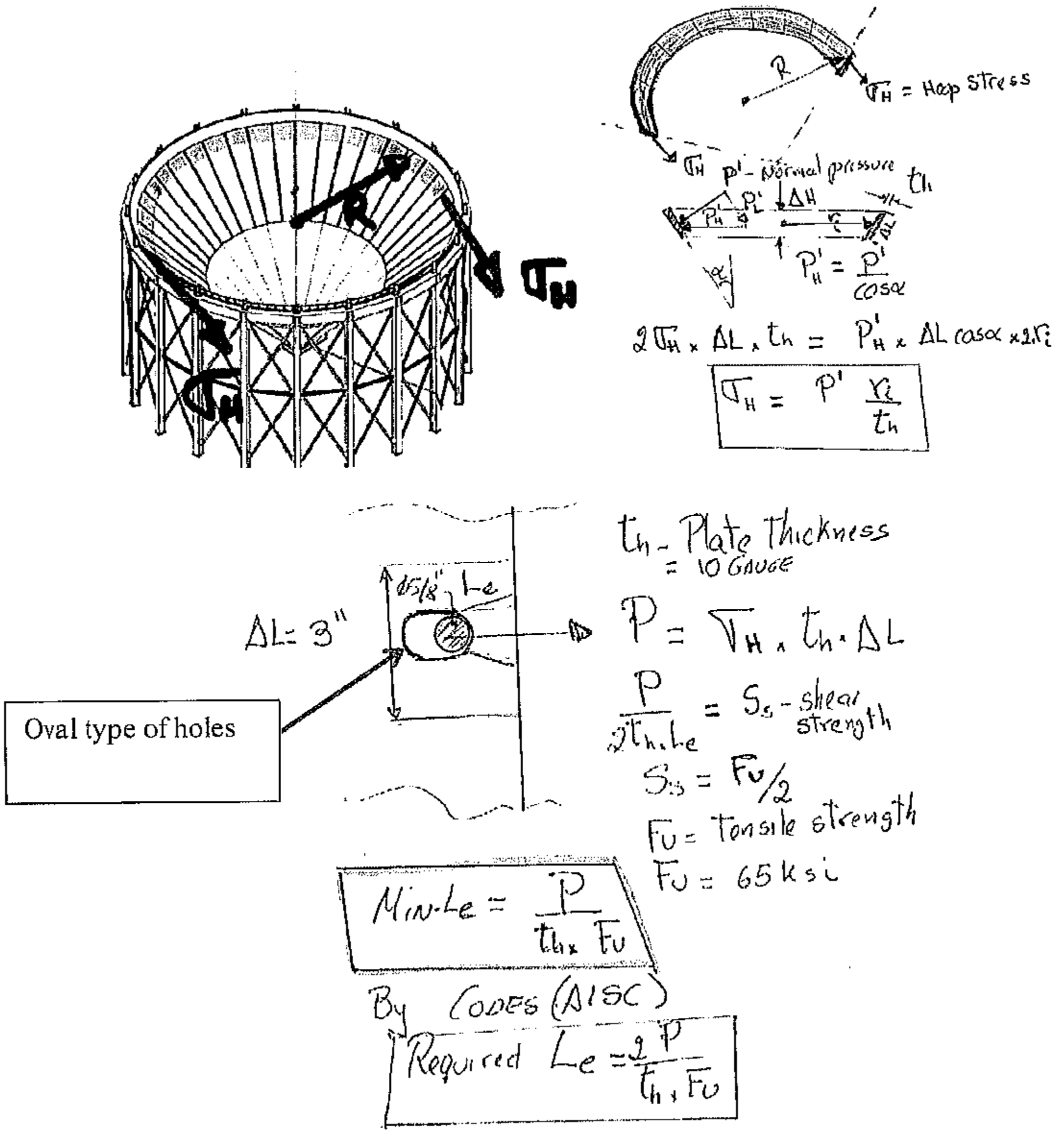

Fig. 7: Stresses on the hopper during flow and Minimum distance required for the bolted connection.

The hoop stresses (σ_h) are proportional to the normal pressure (p') and the radius 'r_i' and inversely proportional to the thickness of the shell on the circumferential/circular cross section of the cone.

Table 1 and Table 2 also show the calculation of the generated hoop stresses at three critical points on the cone, starting at the edge or transition point cylinder-cone point at 42.2 ft. down to 44.5ft. Although the normal pressure on the hopper shell increased at the lower circular strips of the cone, the hoop stress would decrease as the radius of the radius of the circular sections (cone) become smaller (see Fig. 7).

The hoop stress at each circular section of the conical hopper would be transmitted from the laminate to adjacent laminate through/by the bolted connection between those panels (see Fig. 8) and as it was stated earlier in this report those hoop acting perpendiculars to the seams, would pull the seams apart.

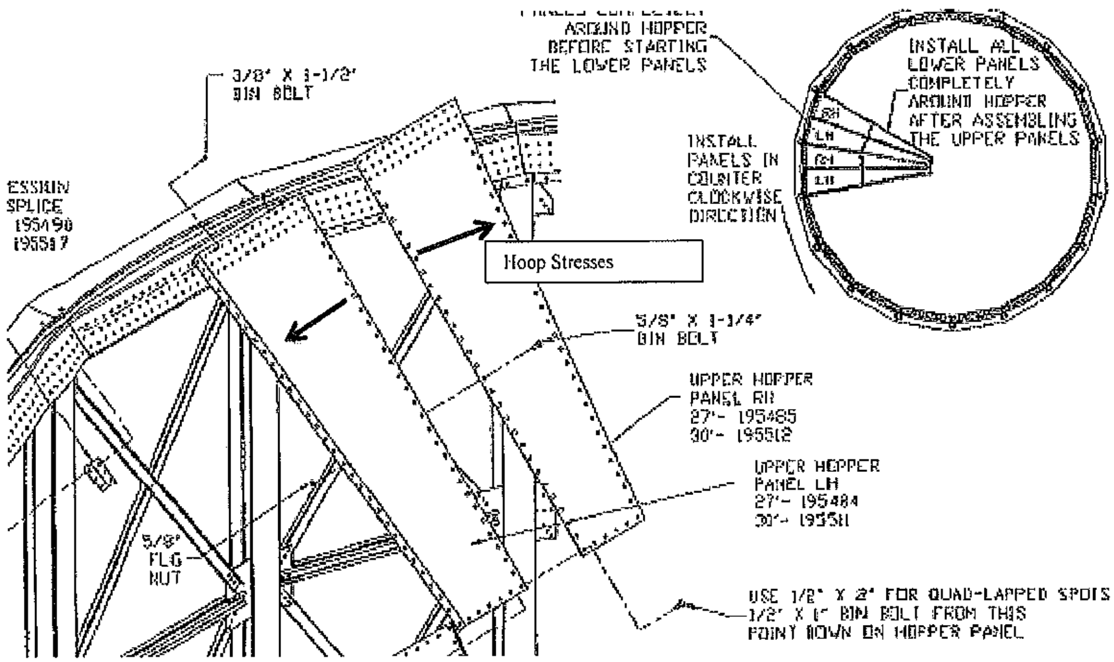

Fig. 8: Hoop/Circumferential Stresses.

According to the '30' HOPPER CONE' hopper assembly of this silo, there are two types of laminate or panel configurations which make up the upper tier of the hopper cone, the 'Upper RH' and 'Upper LH' type laminates. The details of those two panels are illustrated in Fig. 9. Along the four edges of these panels there are the bolt bores (on the seams sides at 3 inches apart from each other, ΔL) for the bolt connections with their adjacent panels. Both types of panels have along one side, that would make up the vertical seams, oval types of holes or slots for the bolted connection (see Fig. 7), and the distance 'Le' from the hole edge to the laminate edge is different for each type. As shown in the formulas of Fig. 7, that distance 'Le' plays a huge role in the strength of the bolted connection towards not inducing a bearing type of failure on the panels' edges due to the forces/stresses conveyed through the bolted joint at the seams. Based on the panel drawings, in theory the 'Upper LH' panel type had a distance 'Le' of 0.719 inches and the 'Upper RH' had a distance 'Le' of 0.875 inches approximately (see Fig. 10).

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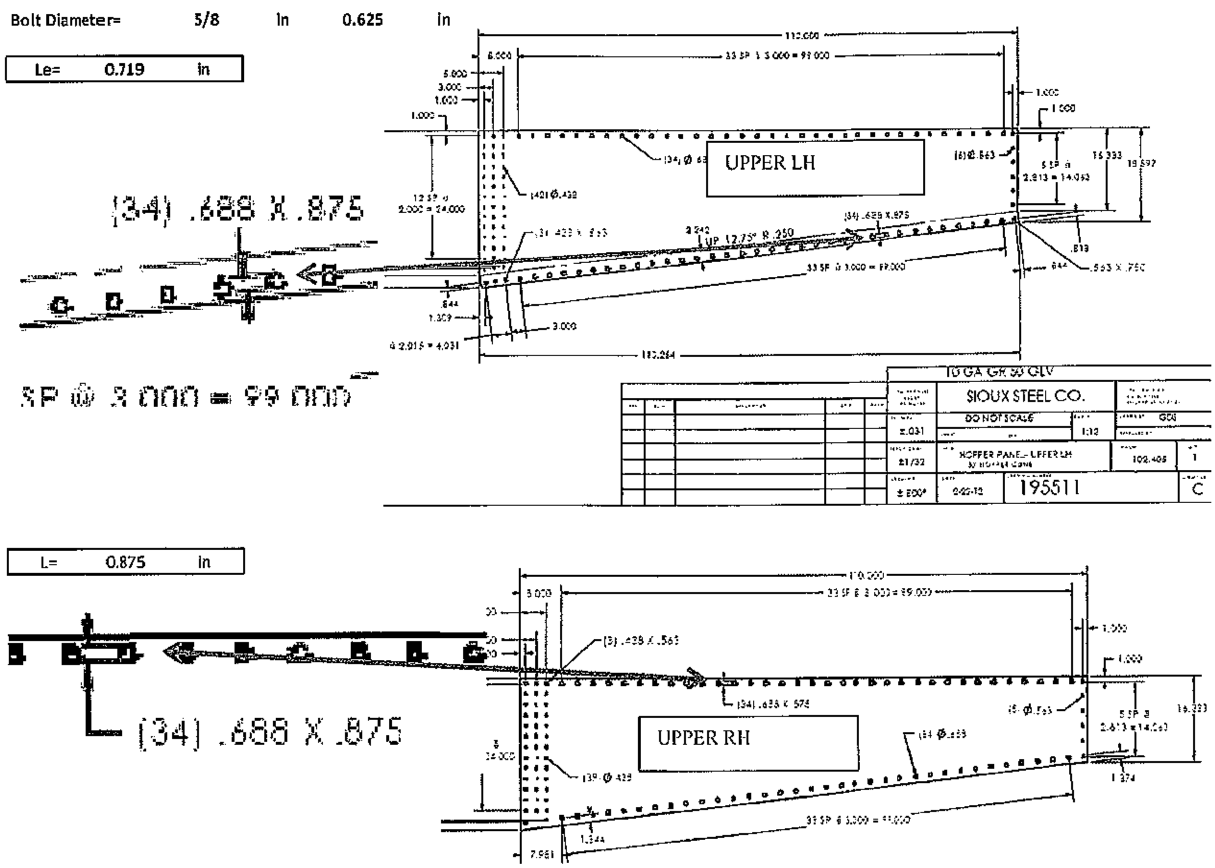

Fig. 9: Details of hopper 'Upper RH' and 'Upper LH' type laminates and their bolt holes configuration.

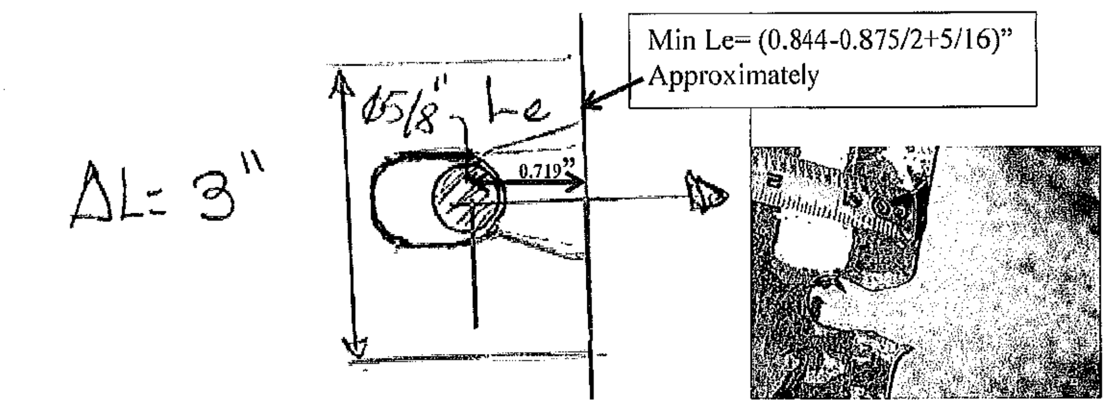

Fig. 10: Details of Panel LH 'Le' calculation.

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b) Failure:

Table 1 and Table 2 also show what would be the actual distance 'Le' in order to not have a bearing failure at the bolted joints at the three points of the cone considered. Actually, a minimum 'Le' value of 0.53" on the bolted connections at about 1 ft. from the top of the hopper cone (43.5) would be required for the initial conditions when the silo was started to be emptied, to avoid a failure; that distance was very close to that which was actually existing at the seam bolted joints of 0.719". However, the failure did not occur until after about 10 to 15 minutes of the beginning of the empting of the material; at which time, the pressure of the material had decreased. Table 3 shows calculations of the stresses and minimum required 'Le' values for not having shear failure on the laminates' edges on the bolted connections for different elevations after the empting process had started and Volumes of 90% and 80% had been reached.

Table 3: Stress Analysis for the hopper section of the referenced silo when filled with soybean meal at 90% and 85% of its maximum capacity.

H (ft)	V (psf)	V (psi)	pl (psi)	σ_t (psi)	P (lb)	Leactual (in)	Lereq (in)
0	0.0	0.00		$H=(V-\pi R^3/3)/\pi R^2$			
5	217.0	1.51					
10	419.2	2.91		Vm=	36102	ft3	
15	607.7	4.22		V=	90	%	
20	783.3	5.44		V=	32491.8	ft3	
25	946.9	6.58		H=	41.0	Top of Cone	
30	1099.4	7.63					
35	1241.5	8.62					
40	1373.9	9.54					
41	1399.3	9.72	8.80	11776.53	4751.8	0.54	1.09
42	1424.4	9.89	8.96	11188.01	4514.4	0.52	1.03
43	**1449.0**	**10.06**	**9.11**	**10568.86**	**4264.5**	**0.49**	**0.98**

H (ft)	V (psf)	V (psi)	pl (psi)	σ_t (psi)	P (lb)	Leactual (in)	Lereq (in)
0	0.0	0.00		$H=(V-\pi R^3/3)/\pi R^2$			
2.4	106.1	0.74					
7.4	315.8	2.19		Vm=	36102	ft3	
12.4	511.3	3.55		V=	85	%	
17.4	693.5	4.82		V=	30686.7	ft3	
22.4	863.2	5.99		H=	38.4	Top of Cone	
27.4	1021.4	7.09					
32.4	1168.9	8.12					
37.4	1306.2	9.07					
38.4	1332.6	9.25	8.38	11214.78	4525.2	0.52	1.04
39.4	1358.5	9.43	8.54	10671.06	4305.8	0.49	0.99
40.4	**1384.1**	**9.61**	**8.70**	**10095.55**	**4073.6**	**0.47**	**0.93**

According to the calculations presented apparently a failure would not have occurred; however, some other aspect for the empting process flow has to be considered to obtain the actual pressures and stresses that existed at the moment of the accident.

The stored material had been in repose in the bin for about 4.5 days before the discharge process started. Also, the day before was rainy and the environment conditions (relative humidity, temperature, etc.) during those days varied considerably from one day to another, and when taking into consideration the 4.5 of repose time in conjunction to those environmental conditions; that combination then propelled extra and uneven consolidation of the soybean meal. That consolidation problem, along with the propeller of this consolidation in a silo, have been studied for years and have been well documented; as can be seen in the references at the end of this report.

The uneven stored material consolidation causes an erratic flow of the material during discharge process due to material 'arching or bridging' formations and then their eventual collapse that would cause extra dynamic loads which would cause extra pressures or 'overpressures' on the cone shell (Ref. 6 and 11). As the material empting process continues those bridging-collapse mechanisms keep occurring as the bottom material layers flow down; this type of flow pattern is also called 'plug flow'.

We were informed that based on the footage of an owner's surveillance video, which recorded the accident; that just before the time of the accident, the out coming flow from the bottom hopper was erratic and that one of the workers was banging the exterior shell of the hopper to help the out-flow out of the material. Also, we were informed that the flow helper air cannons were operating as puffs of dust could be observed from the video.

To estimate or consider the overpressure effects caused by the plug flow, it is recommended that the normal pressures on the silo based on the Janssen equations are multiplied by a factor of 1.4 (40% of extra pressure) to consider the dynamic effect of the bridging-collapse effects mechanism. Those factors have been considered based on the studies developed by Platonov and Kovtun in 1959 (Ref. 11).

If we included that overpressure effect on the values obtained in Table 3, then the values shown in Table 4 would be obtained. Based on the results shown in Table 4 it is evident that a seam failure would have occurred as the 'Upper LH' panels or laminates had a distance 'Le' of 0.719 inches and the minimum required 'Le', for preventing the bearing failure at the bolted joints at the seams at a location just below the cone, would be greater than that after the empting process had started.

The majority of the panels, where their edges failed, were the 'LH' type and the failures started at about 1 ft. below the top of the hopper cone (see Fig. 11). After one of the bolted joints failed at each seam then the adjacent joints were not able to resist the extra stresses conveyed to them and a chain reaction type of failure occurred all the way down the seams from the initially failed joint.

Discussion about Findings and Responsibilities

a) General Discussion:

Based on the analysis presented in this report it is evident that the referenced hopper would have failed under the loading and material condition existing at the day of the accident. However a silo should be designed to consider all the loading, repose and discharge conditions of the material and this silo did not comply with that sound design.

Most of the silo design standards consider the methods to calculate the pressures due to the stored material under different conditions of operation. Also, the standard for the structural design of this steel silo, as the referenced one such as the "American Institute of Steel Construction' or AISC, provides the guidelines for designing the different parts of a steel silo.

Table 4: Stress Analysis for the hopper section of the referenced silo when filled with soybean meal at 90% and 85% of its maximum capacity considering the 'Plug Flow Factor'.

H (ft)	V (psf)	V (psi)	p (psi)	σ_n (psi)	P (lb)	Leactual (in)	Lereq (in)
2	124.1	0.86		$H=(V-\pi R^3/3)/\pi R^2$			
5	303.8	2.11					
10	586.9	4.08		Vm=	36102	ft3	
15	850.7	5.91		V=	90	%	
20	1096.6	7.62		V=	32491.8	ft3	
25	1325.7	9.21		H=	41.0	Top of Cone	
30	1539.2	10.69					
35	1738.1	12.07		Considering the 1.4 factor due to			
40	1923.5	13.36		Plug Flow type			
41	1959.1	13.60	12.32	16487.14	6652.6	0.76	1.52
42	1994.1	13.85	12.54	15663.22	6320.1	0.72	1.45
43	**2028.6**	**14.09**	**12.76**	**14796.40**	**5970.3**	**0.68**	**1.37**
H (ft)	**V (psf)**	**V (psi)**	**p (psi)**	**σ_n (psi)**	**P (lb)**	**Leactual (in)**	**Lereq (in)**
0	0.0	0.00		$H=(V-\pi R^3/3)/\pi R^2$			
2.4	148.5	1.03					
7.4	442.2	3.07		Vm=	36102	ft3	
12.4	715.9	4.97		V=	85	%	
17.4	970.9	6.74		V=	30686.7	ft3	
22.4	1208.5	8.39		H=	38.4	Top of Cone	
27.4	1430.0	9.93					
32.4	1636.4	11.36		Considering the 1.4 factor due to			
37.4	1828.7	12.70		Plug Flow type			
38.4	1865.6	12.96	11.73	15700.69	6335.2	0.72	1.45
39.4	1902.0	13.21	11.96	14939.48	6028.1	0.69	1.38
40.4	**1937.8**	**13.46**	**12.19**	**14133.78**	**5703.0**	**0.65**	**1.30**

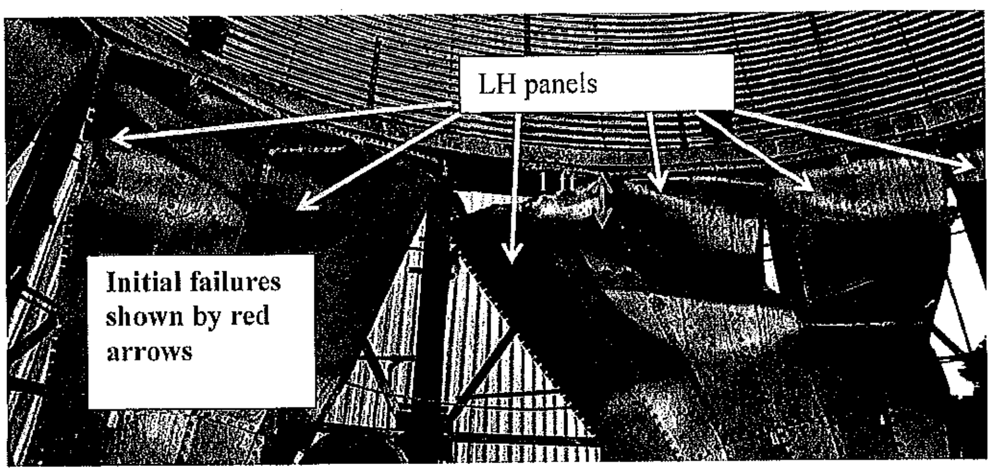

Fig. 11: 'Upper LP' Panels failure.

The American Standard ANSI/ASAE EP433 DEC1988 (R2011) "Loads Exerted by Free-Flowing Grain on Bins" accounts for and/or describes the calculation of the pressure in the bin due to bulk material during discharge flow. However, two types of flows can occur, funnel flow and or plug flow, and the overpressures due to these type of flows are described/developed in section '4.1.2 Dynamic Pressure'. Part of this section reads:

> "4.1.2 Dynamic pressures
>
> 4.1.2.1 Funnel flow. Funnel flow bins have lateral wall pressures predictable by equation 2. Funnel flow will normally occur in bins which have H/D ratios less than 2.0. H is measured from the lowest point of discharge to the top of the grain surface, or if a surcharge is present, to 1/3 of the surcharge height (see Fig. 3).
>
> 4.1.2.2 Plug flow. Dynamic lateral wall pressures during plug flow are larger than those predicted by equation 2. Bins with an H/D ratio greater than 2.0 may unload by plug flow. Estimate lateral wall pressure in bins which unload by plug flow by the static pressure determined using equation 2 multiplied by an overpressure factor. Values of the overpressure factor, F, are given in Table 1. For flat bottom plug flow bins apply this factor from the grain surface to within a distance of D/4 from the bottom".

The H/D ratio of the incident silo is about 2, which means that it is very likely the occurrence of a plug flow type. In addition and specifically for the hopper section of the bin in Section '4.2 Hopper pressures' and part of its Subsection '4.2.2.1 Normal pressures' reads as follows:

> "……..Use the bin geometry at the intersection of the hopper and the bin wall to calculate hydraulic radius. Apply overpressure factors at the top of the hopper. Overpressure factors may be linearly reduced from F at the top of the hopper to 1.0 at the point of hopper discharge".

And the overpressure factors are given in Table 1 of this standard which is shown in Fig. 12.

Table 1 – Overpressure factors and material properties

Wall material	μ	*k*	*F*
Steel	0.30	0.5	1.4
Concrete	0.40	0.5	1.4
Corrugated steel	0.37	0.5	1.4

Fig. 12: Design factors from ANSI/ASAE EP433 DEC1988 (R2011).

The AISC regulates that for any bolted connection a safety factor (FS-factor of safety) of 2 should be considered. Therefore, if a FS of 2 is considered the calculated 'Le' values would double. Those required values by code are specified in those tables by 'Lereq'; and for a full capacity design (100%) the holes 'Le' of the bolted joints at the seams of the hopper, at the top section of the cone, should have been of 1.6 inches (see Table 5). Based on the analysis presented in this report it can be concluded that all the actual silo's bolted joints were defectively and/or deficiently designed according to the regulating of design and construction codes applicable for silo designs.

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Additionally the AISC limits the minimum distances 'Le' according the bolt diameter (in this case at Diameter 5/8") as illustrated in Fig. 13. Those minimum distances 'Le' were not kept in the design of this silo.

Table 5: Stress Analysis for the hopper section of the referenced silo when filled with soybean meal at 100% of its maximum capacity considering the 'Plug Flow Factor'.

H (ft)	V (psf)	V (psi)	p (psi)	σ (psi)	P (lb)	Leactual (in)	Lereq (in)
7.1	425.1	2.95		$H=(V-\pi R^3/3)/\pi R^2$			
10.1	592.4	4.11					
15.1	855.8	5.94		Vm=	36102	ft3	
20.1	1101.3	7.65		V=	100	%	
25.1	1330.1	9.24		V=	36102	ft3	
30.1	1543.3	10.72		H=	46.1	Top of Cone	
35.1	1742.0	12.10					
40.1	1927.1	13.38		Considering the 1.4 factor due to			
45.1	2099.6	14.58		Plug Flow type			
46.1	2132.7	14.81	13.41	17948.46	7242.2	0.83	1.66
47.1	2165.3	15.04	13.62	17008.01	6862.7	0.78	1.57
48.1	2197.4	**15.26**	**13.82**	**16027.64**	**6467.2**	**0.74**	**1.48**

We also had the opportunity of collecting some material samples of the hopper shell to perform tensile tests to corroborate the mechanical property of the material. The material of the hopper panels was called per the design drawing as a Grade 50 galvanized steel and the tensile tests performed for the collected samples confirmed the strength of that steel material to be as specified.

TABLE J3.4
Minimum Edge Distance,[a] in., from Center of Standard Hole[b] to Edge of Connected Part

Bolt Diameter (in.)	At Sheared Edges	At Rolled Edges of Plates, Shapes or Bars, or Thermally Cut Edges [c]
1/2	7/8	3/4
5/8	1 1/8	7/8
3/4	1 1/4	1
7/8	1 1/2 [d]	1 1/8
1	1 3/4 [d]	1 1/4
1 1/8	2	1 1/2
1 1/4	2 1/4	1 5/8
Over 1 1/4	1 3/4 × d	1 1/4 × d

[a] Lesser edge distances are permitted to be used provided provisions of Section J3.10, as appropriate, are satisfied.

[b] For oversized or slotted holes, see Table J3.5.

[c] All edge distances in this *column* are permitted to be reduced 1/8 in. when the hole is at a point where *required strength* does not exceed 25 percent of the maximum strength in the element.

[d] These are permitted to be 1 1/4 in. at the ends of *beam connection* angles and shear end plates.

Fig. 13: Minimum edge distanced in bearing type bolted connections by AISC.

b) Original Structural Calculations Review:

ESI was provided with the engineering and structural analysis for the referenced Sioux-30' diameter hopper type silo performed by 'KC Engineering' (hereinafter KC) located in Sioux City, Iowa. From the document provided to ESI we could verify that this engineering analysis did not consider or include any calculation for the bolted connections of the vertical seams of the hopper. The only connections that were calculated by KC were the top connections of the hopper with the ring of the bottom of the cylinder of the silo (see Fig. 14).

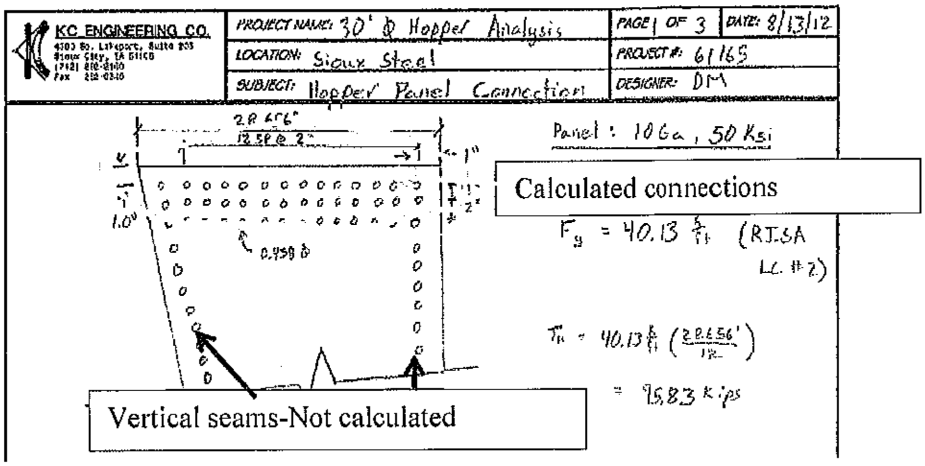

Fig. 14: Hopper panel connection calculations from KC.

We could also verify that KC used and overpressure factor at 1.4 (see Fig. 15) as estimated by ESI and their calculated pressures on the hopper shell resulted at about the same level as the ESI's calculated ones.

The lack of the consideration for or the overlooking of the hoop stresses effect on the bolted connections of the silo hopper seams in the structural analysis performed by KC can be considered as a serious engineering oversight; an oversight that actually was the principal cause of the failure of this hopper silo. In an engineering analysis of this importance and level in which individuals' lives can be in jeopardy, it is mandatory to check all the structural members of the structure, such as the bolted connections

Conclusions and Opinions

Based on our inspection findings, document review and engineering analysis of all the facts, we now present the following conclusions and opinions with regard to Sioux Silo Failure Investigation.

- It could be corroborated that the root cause of the failure of the hopper section of the referenced silo was that the hopper shell split open at the seams. It is evident that some fasteners that were used to attach the hopper laminates together, tore through the ends of the laminates' edges causing a bearing type of failure of the bolted joint due to shear stresses (on the laminate edges).

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- Based on the analyses performed in this report it is clear and evident that hoop stresses (or circumferential stresses) acting perpendicular to the seams, pulled those seams apart and then caused the failure of some bolted joints or connections at those seams of the hopper. The accident occurred when the material was being discharged. Based on the loading of the silo reported at 93% of full capacity at the time of the accident, the material height in the cylindrical part of the bin was at about 42.5 ft.

- The vertical seams of the hopper failed due to 'bearing' type of failure on the panels' edges due to the forces/stresses conveyed through the bolted joint at the seams by the created hoop stresses. The required distance 'Le' of the vertical connections (vertical seams) for avoiding a bearing type of failure was insufficient, which thereby propelled the failure of the hopper.

- The majority of the panels, where edges failed, were the 'LH' type and the failures started at about 1 ft. below the top of the hopper cone (see Fig. 11). After one of the bolted joints failed at each seam the adjacent joints were not able to resist the extra stresses conveyed to them and a chain reaction type of failure occurred all the way down the seams from the initially failed joint.

- The design of the hopper's vertical seam bolted connections was deficient and inappropriate for the loading capacity of the affected silo.

- According to the documents review, the responsible company 'KC Engineering' in charge of performing the structural and engineering analysis of the referenced silo; omitted taking into consideration the calculations of the bolted connections of the vertical (lateral) seams of the hopper assembly.

- The lack of the consideration or oversight of the hoop stresses effect on the bolted connections of the silo hopper vertical seams in the structural analysis performed by KC can be considered as a serious engineering oversight; an oversight that actually was the principal cause of the failure of this hopper type silo. In an engineering analysis of this importance and level, in which individuals' lives can be in jeopardy, it is mandatory to check all the structural members of the structure, such as all bolted connections, in order to avoid disastrous consequences.

- It is ESI's opinion that erection defects did not exist, as the silo was erected on site according to the drawings and specifications.

- The material of the panels used on the fabrication of the hopper was under specification; tensile tests were performed in order to corroborate that fact.

- ESI is still on the investigation process of this incident and if any further or additional information is received additional conclusions might be reached.

KC Engineering, P.C.

Project Name:	30' Diameter Hopper Analysis	Date:	8/8/2012
Location:	Sioux Steel	Project #:	61165
Subject:	Grain Pressures and Wall Loads - 30' Diameter Hopper	Designer:	DJM

Calculate Grain Pressures and Wall Loads on a Circular Steel Bin using ANSI/ASAE EP433:

Note: This spreadsheet and ASAE EP433 shall to be used only for the design of foundations for steel bins. Concrete silos shall be designed using ACI 313 with conservative modifications in accordance with the Midwest Plan Service handbook and shall not be designed using this spreadsheet.

Input Variables for use in Janssen's Formula:

bulk density of grain, W =	55.3 pcf	use 48 for corn or beans, < or = 52 for any grain
emptying angle of internal friction, ϕ =	27 degrees	use 27 for shelled corn, 29 for soybeans
filling angle of repose, α =	23 degrees	use 23 for shelled corn, 25 for soybeans
coefficient of friction of grain on wall, μ =	0.37	use 0.3 for smooth steel, 0.37 for corrugated steel
k =	0.50	always use 0.5 when using ASAE EP433
Diameter of Tank, D =	30 ft	
Hydraulic Radius of Tank, R =	7.5 ft	
height of grain at wall, Hs =	51.3 ft	

Calculate grain heights, determine whether bin is deep or shallow, and calculate Overpressure Factor, F:

height to top of grain at apex, Ht =	57.7 ft	
height of grain to 1/3 height of surcharge, H =	53.5 ft	
height at which rupture plane intersects =	24.5 ft	< than Hs, therefore use eq. for Deep Bins
→ Overpressure Factor, F =	1.4	1.0 for shallow bins, 1.4 for deep bins

Fig. 15: Part of the general data used for the silo engineering analysis by KC.

References:

1. Youssef A.; 'Structural Design of Steel Bins and Silos'.
2. Jenike & Johanson Inc. 'Silo Design'.
3. Smith K. Milo; "The Design of Walls, Bins and Grain Elevators".
4. J. Carsona and D. Craig; "Silo design codes: Their limits and inconsistencies". Procedia Engineering.
5. AS 3774- Australian Standard; 'Loads on Bulk Solids Containers'.
6. ANSI/ASAE EP433 DEC1988 (R2011); "Loads Exerted by Free-Flowing Grain on Bins".
7. E. Maynard; "Ten Steps to an Effective Bin Design".
8. J.W Carson and R.T. Jenkyn; "Load Development and Structural Consideration in Silo Design".
9. J. M. Rotter; "Silo and Hopper Design for Strength". Bulk Solids Handling: Equipment Selection and Operation Edited by Don McGlinchey.
10. G. G. Chase, University of Akron; "HOPPER DESIGN". Solid Notes.
11. Platonov, P.N. and A.P. Kovtun; "Pressure of Grain Silo Walls" -1959 cited by Others.

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12. J. M. Boac, M. E. Casada, R. G. Maghirang, J. P. Harner III.; "MATERIAL AND INTERACTION PROPERTIES OF SELECTED GRAINS AND OILSEEDS FOR MODELING DISCRETE PARTICLES". 2010 American Society of Agricultural and Biological Engineers ISSN 2151-0032.
13. M. Molenda, M. D. Montross, J. Horabik, I. J. Ross; "MECHANICAL PROPERTIES OF CORN AND SOYBEAN MEAL". 2002 American Society of Agricultural Engineers ISSN 0001–2351.
14. American Steel Construction (AISC) 360-05; "Specification for Structural Steel Buildings".
15. Ch. Salmon and J. Johnson; "Steel Structures Design and Behavior", ISBN 0-06-045694-9.

Documents Reviewed:

- Sioux 30' hopper assembly & drawings.
- Sioux 3012 hopper bin - cylinder parts.
- Sioux 173018_BIN_OWNERS_USERS_MANUAL_REV_E.
- Sioux 197870_REV_D_27-36'_HOPPER_BIN.
- Sioux-AirForce Manual-Pneumatic System.
- Sioux Bin Pilot Hole.
- Sioux Bin Template Sioux Steel.
- Sioux Cone Template Sioux Steel.
- Sioux Hopper Material Specifications.
- Sioux HOPPER_CAPACITIES.
- Air Cannons Sequence of Operations.
- Sioux Steel Placement.
- Sioux Steel Cannons Installation Drawing.
- KCE 30' Diameter Hopper Report.
- KCE Addendum Letter #1.

Appendixes:

I-Photos of Inspections

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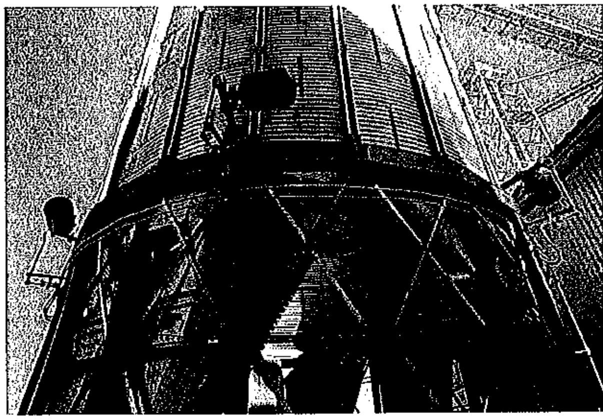

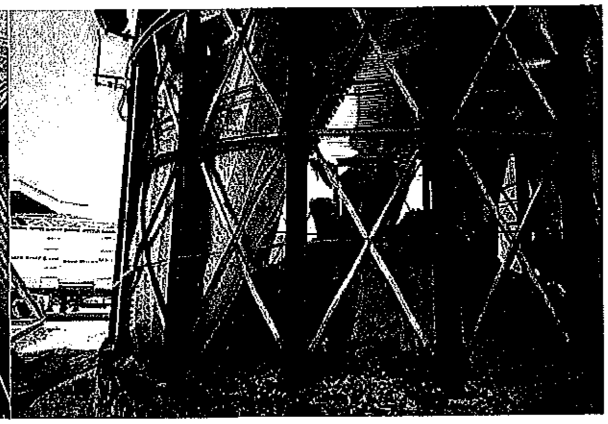

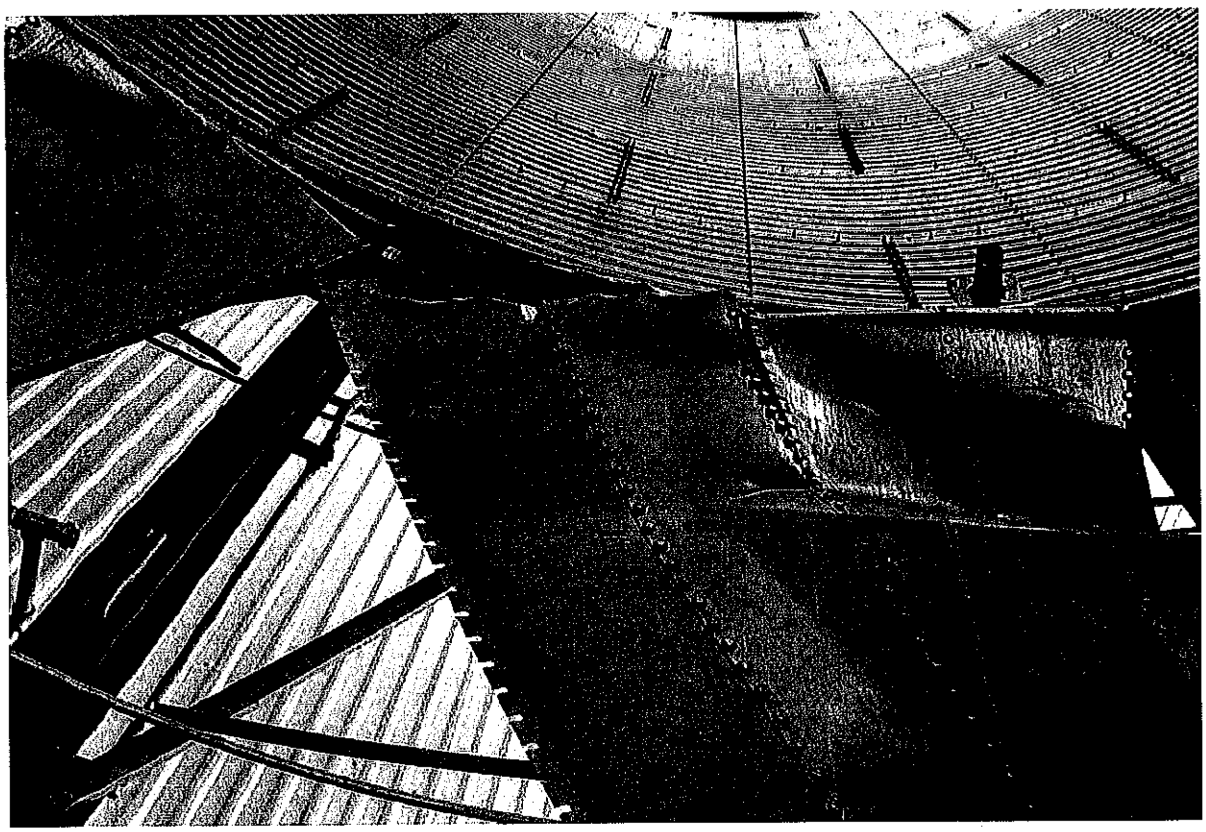

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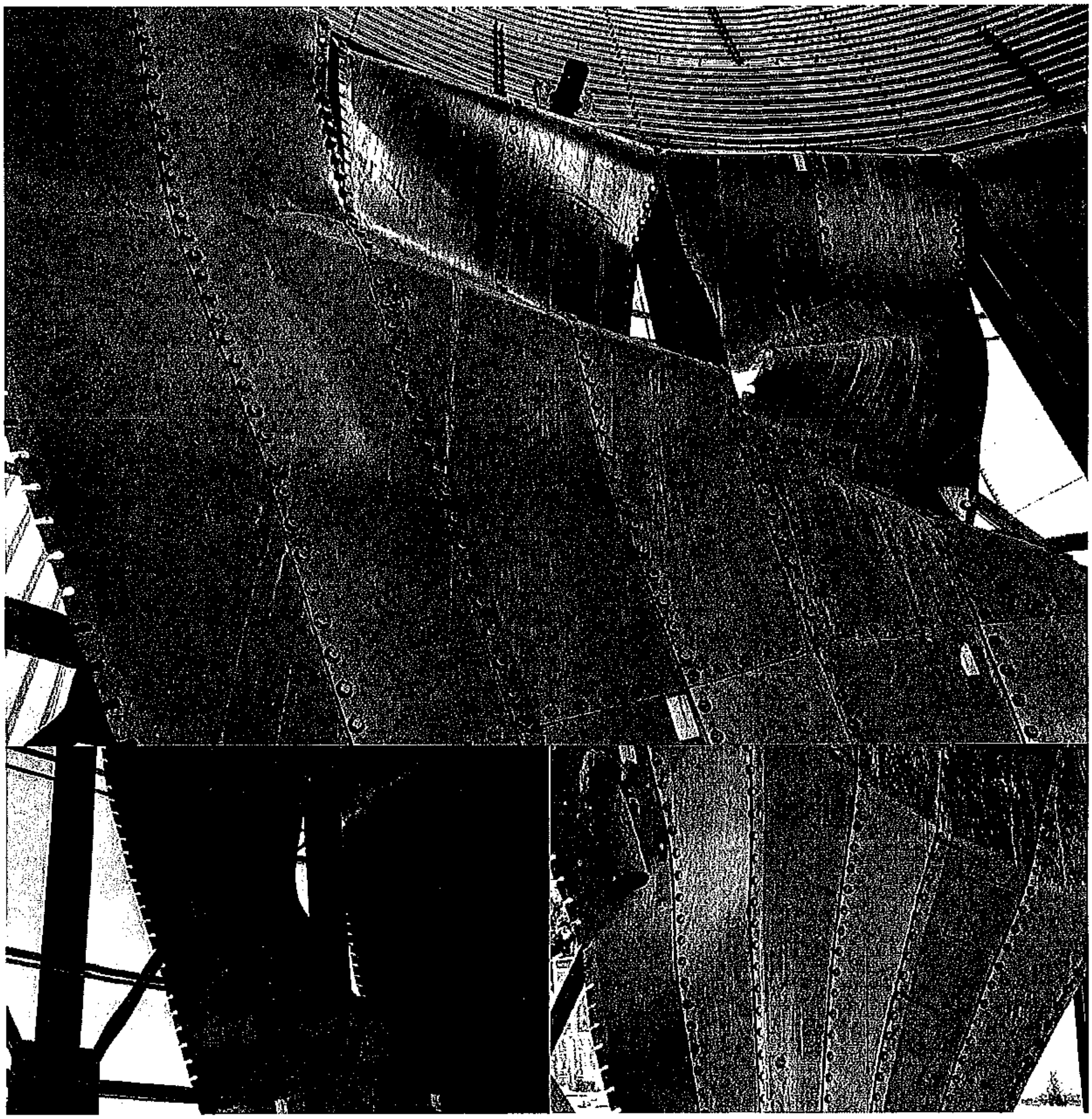

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